Gas in Beta Pictoris-like disks

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Outline

I. β Pictoris

- Discovery of the gaseous component
- Observations

II. The gas location, characteristics and sources

- Where is the observed gas ?
- What are the observed gas characteristics?
- What are the possible sources ?

III. Consequences

- Planets are needed
- Other gaseous debris disks ?
- Age of gaseous debris disks

IV. Conclusions

- Very active post planetary formation phase

How the gaseous component was found

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1984 Smith & Terrile

Coronographic images of an edge-on dust disk

1985 Kondo & Bruhweiler

Fine structure Fe II and C I lines → 10^3 cm^{-3}

Lines from metastable Fe II → possible 10^8 cm^{-3}

Variations over years

1985 Hobbs et al.

1986 Vidal-Madjar et al.

Comparison of Ca II to Na I absorptions

→damping gas needed to stop blow away by radiation pressure

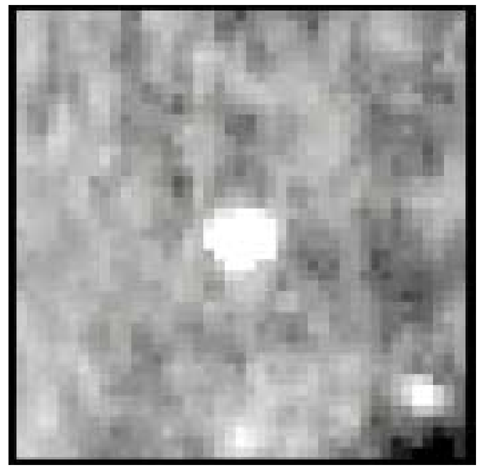
→important circumstellar gas content,

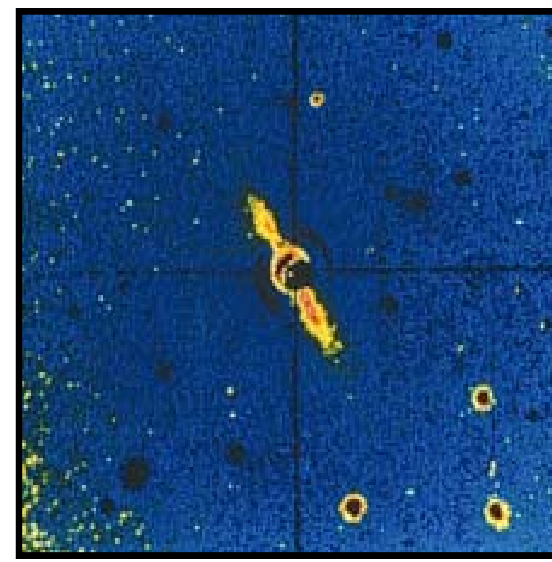
→possible 10^5 cm^{-3} with r^{-1} distribution

1987 Ferlet et al.

Redshifted and variable spectral signatures over days and even hours

→ Infalling gas at up to 40 km/s





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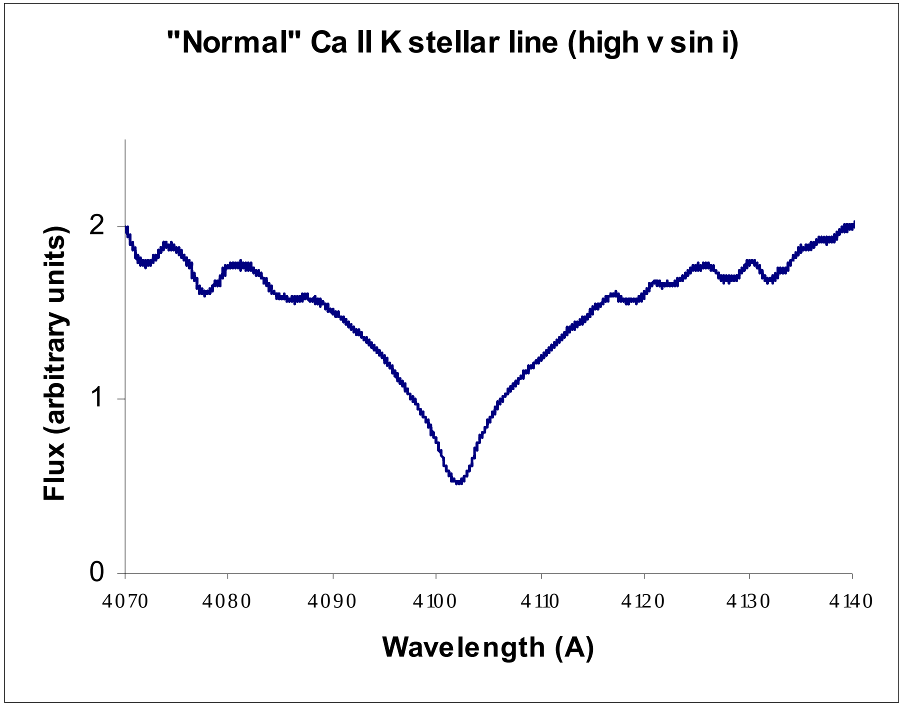

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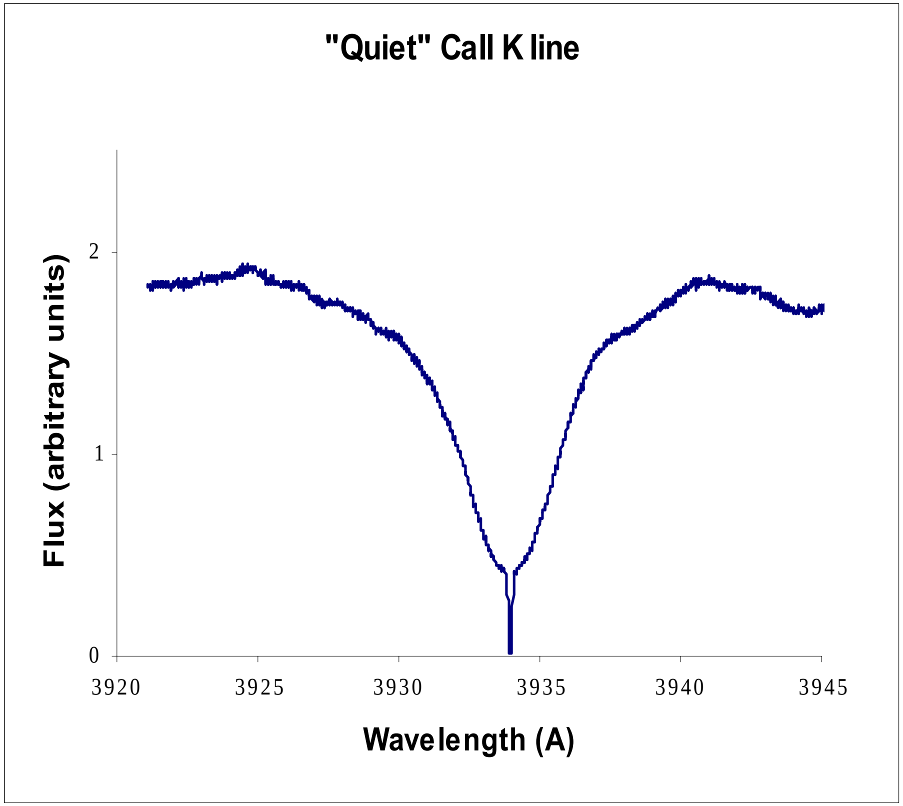

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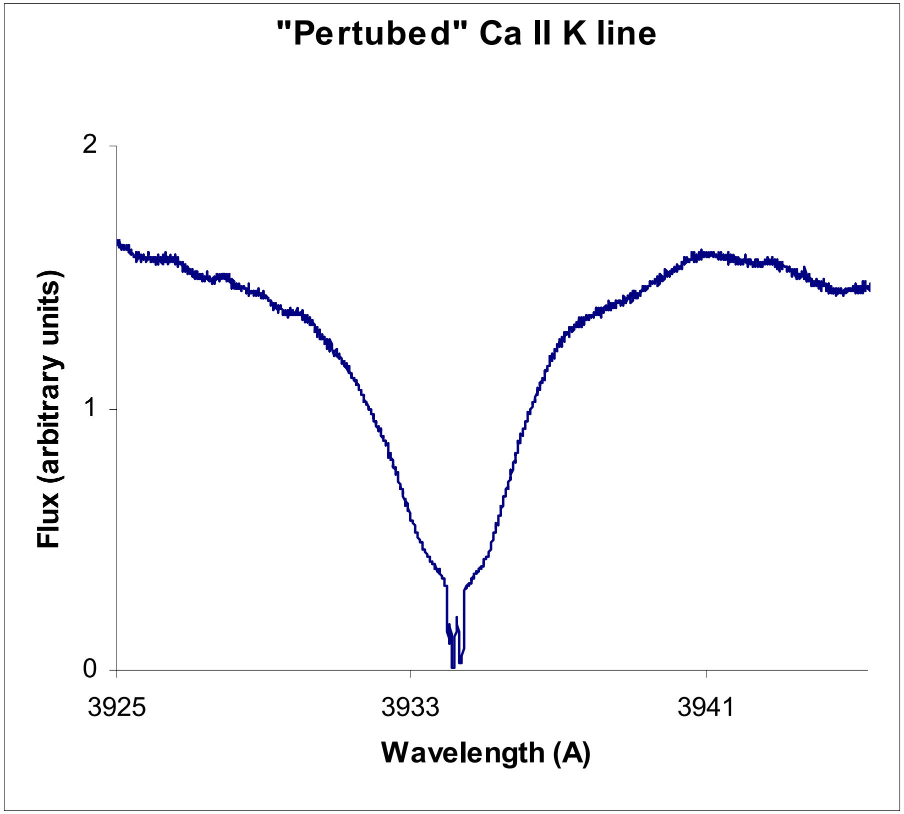

Observations of the Beta Pic gas

Many more lines detected implying :

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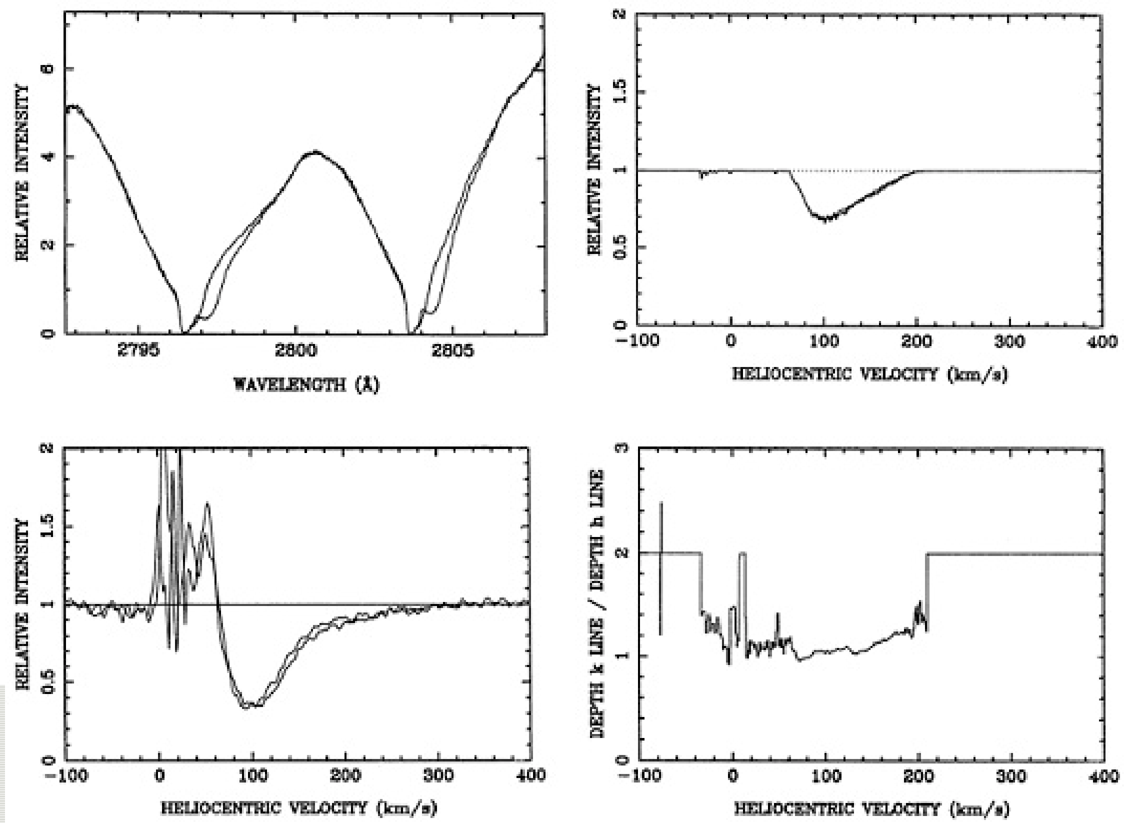

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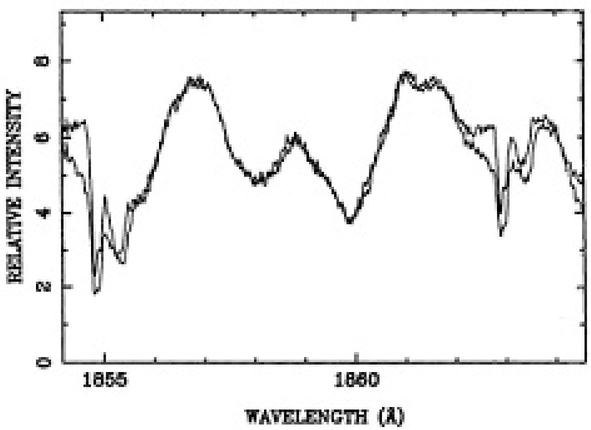

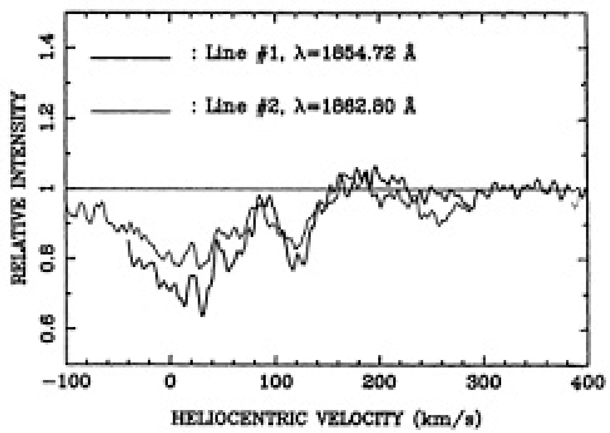

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Jolly et al. 1998
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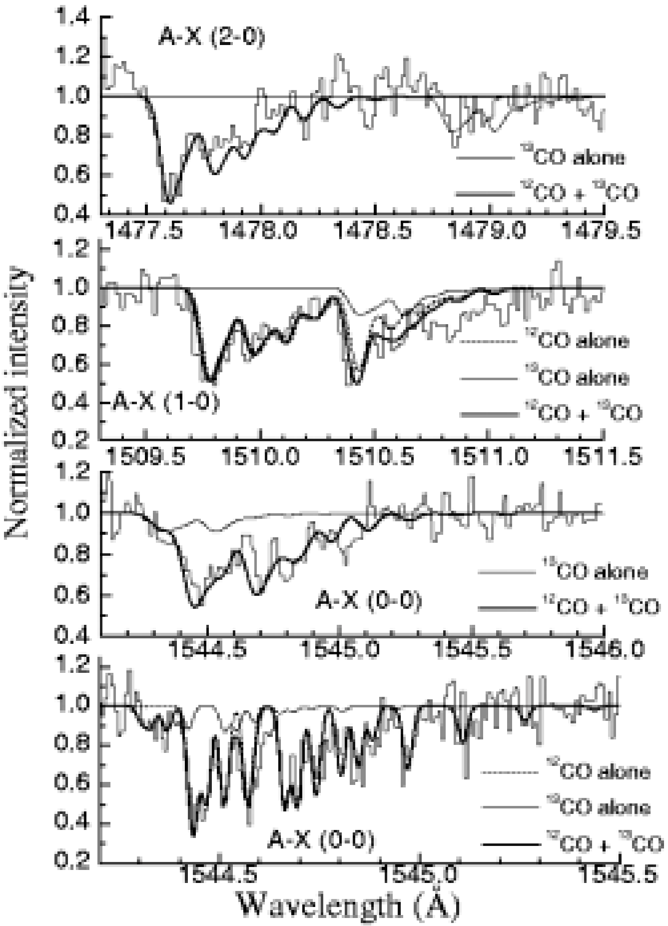

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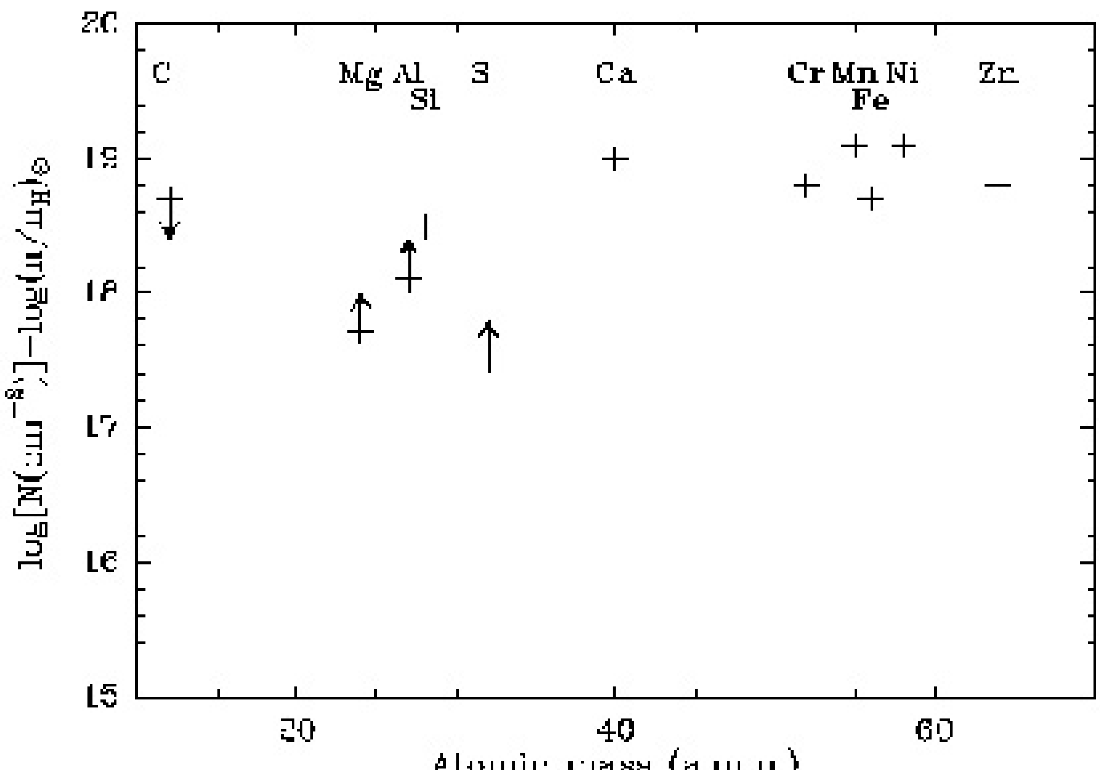

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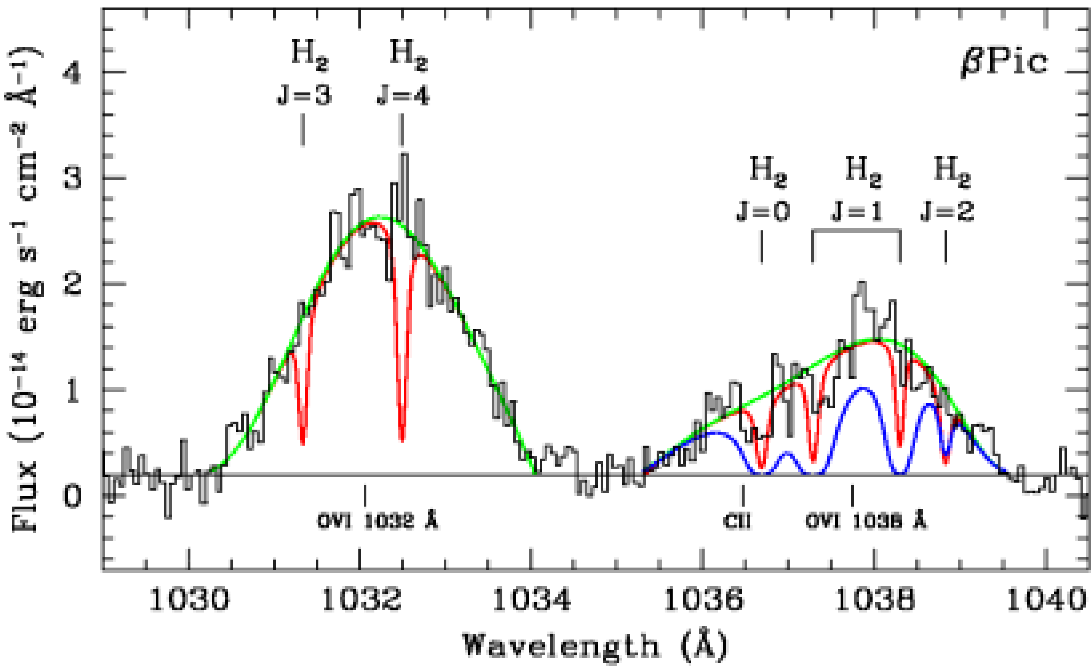

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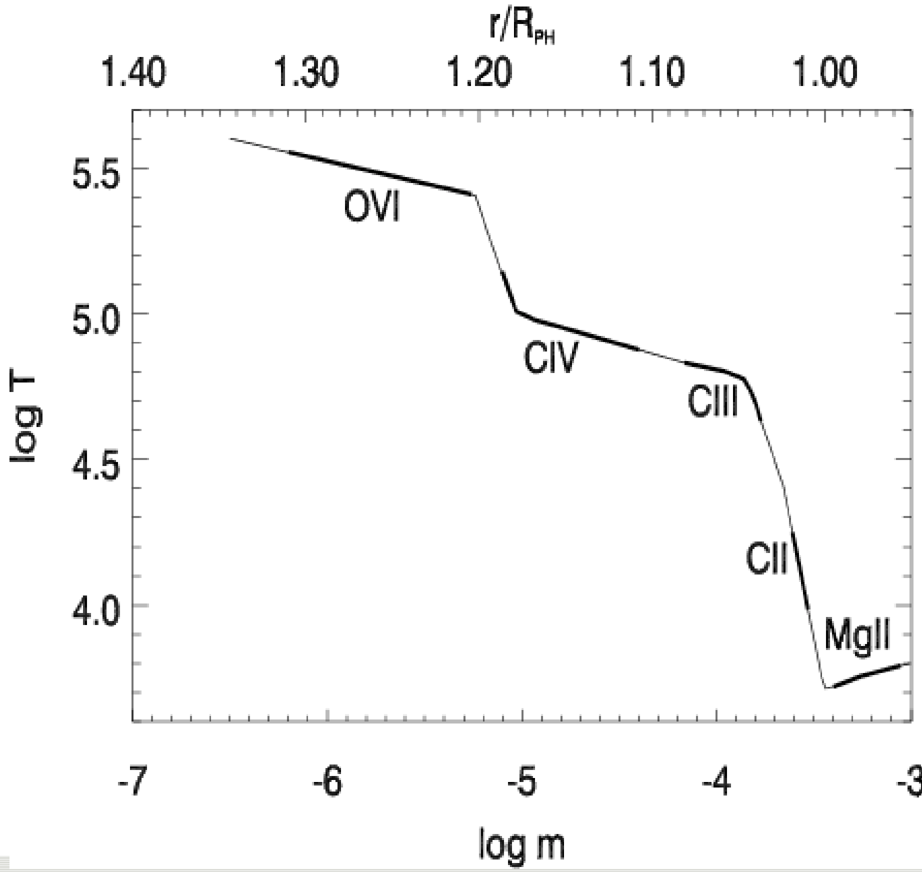
-C III, O VI emissions → chromospheric like structure, high gas content at few R_*
(Deleuil et al. 2001; Bouret et al. 2002)

Deleuil et al. 2001
Bouret et al. 2002

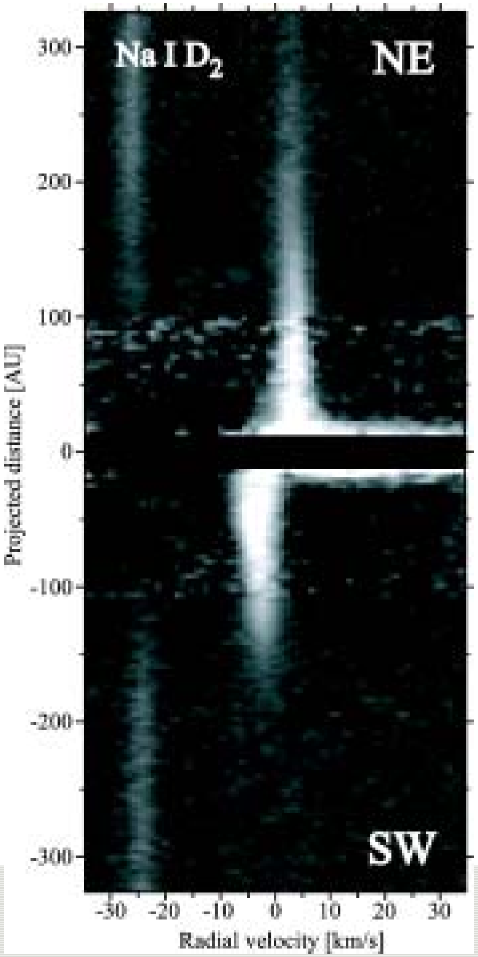


Observations of the Beta Pic gas

New disk emission lines are detected, they show that distant gas (>20 AU):

- is in keplerian rotation
- extends to at least 300 AU
- shows asymmetries similar but more pronounced than dust

Brandeker et al. 2004



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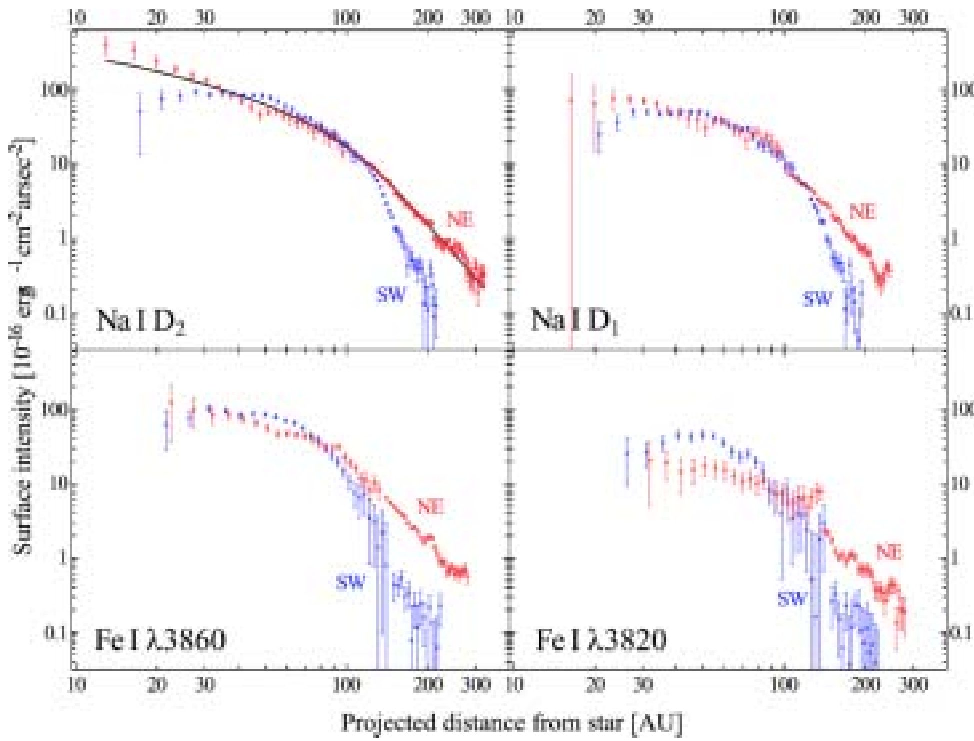

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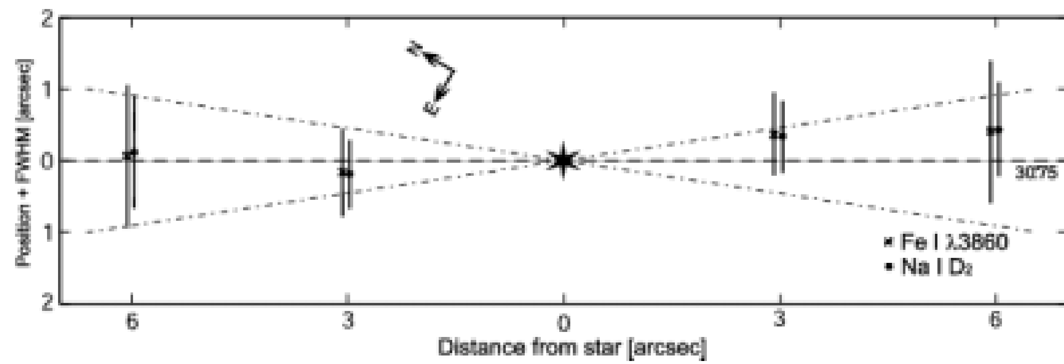

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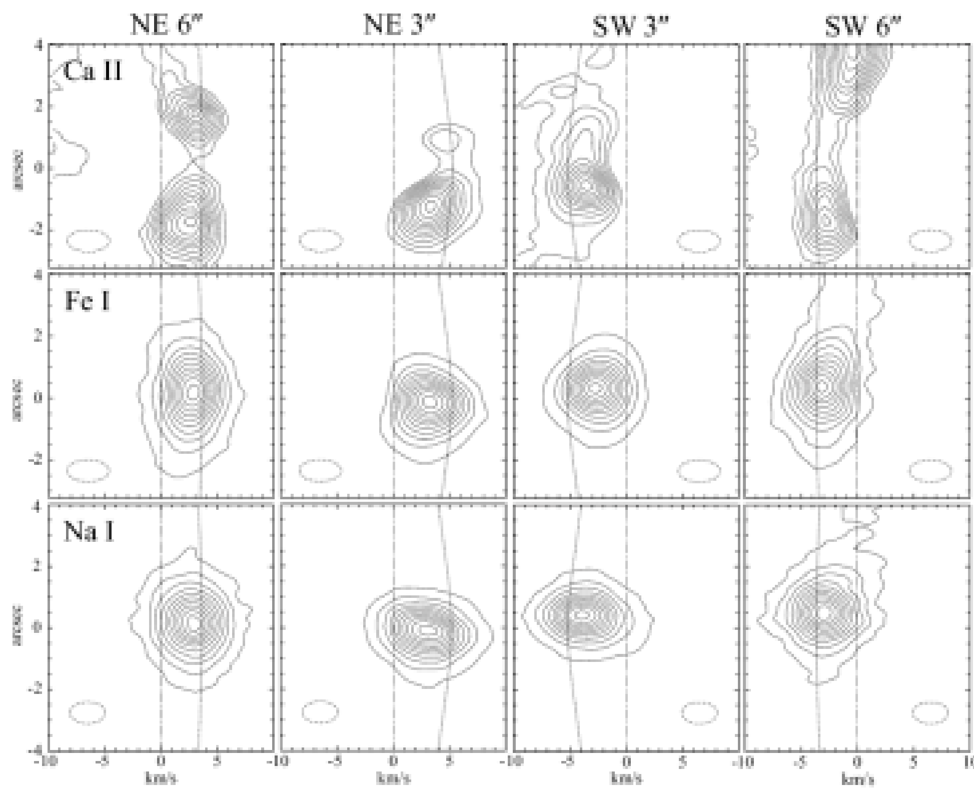
- NaI and CaII have very different distributions

Brandeker et al. 2004



Where is the observed gas ?

- **At few stellar radii *(chromospheric O VI and C III)***
- **Within 1 AU *(hot gas and Ca II triplet)***
- **Within 100 AU *(CO)***
- **Up to at least 300 AU *(direct imaging)***

Vidal-Madjar et al. 2004

What are the gas characteristics?

- **Clumpy** ***(doublet line ratio)***

- **In the 10^3 to 10^8 cm $^{-3}$ range**
  (column densities/disk radius,
  fine structure Fe II and C I lines,
  lines from metastable Fe II,
  damping gas)

- **Recent** ***(CO, C I, etc… lifetimes)***

- **Linked to dust** ***(similar geometry)***

Vidal-Madjar et al. 2004

What are the possible sources ?

- **Evaporation of dust in star infalling material**
  (hot gas, chromospheric-like activity)

- **Comets on eccentric orbits:**
  Falling Evaporating Bodies (FEBs)
  (Variable absorption features)

- **Slowly evaporating asteroids on circular orbits**
  Orbiting Evaporating Bodies (OEBs)
  (cold CO and dust)

Vidal-Madjar et al. 2004

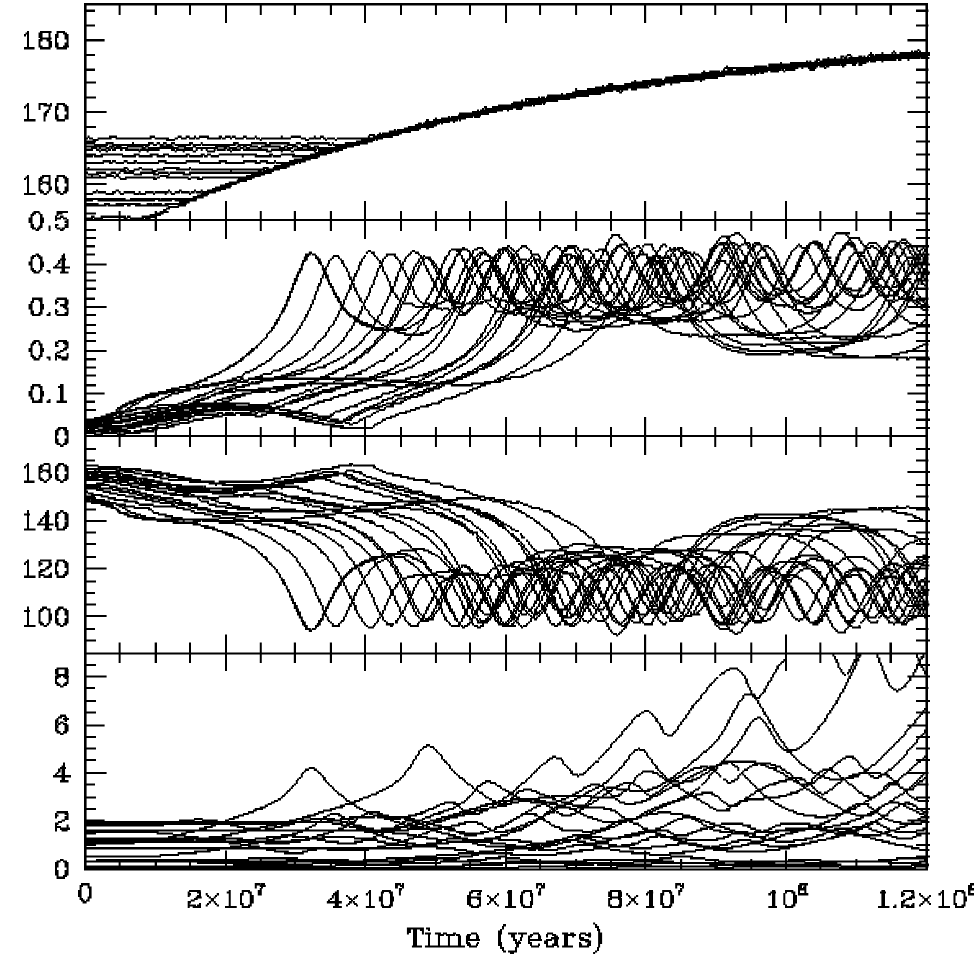
What are the possible sources ?

The Orbiting Bodies scenario

Lecavelier des Etangs et al. 1996
Lecavelier des Etangs 1998

- Dust produced in inner parts can be seen in outer parts.
Scattered light following F α r $^{-5}$.

- Bodies trapped in resonance with a migrating Neptune-like planet can significantly evaporate, producing a dust and gas disk with characteristics similar to the observed ones (CO, asymetries, etc.)



What are the possible sources ?

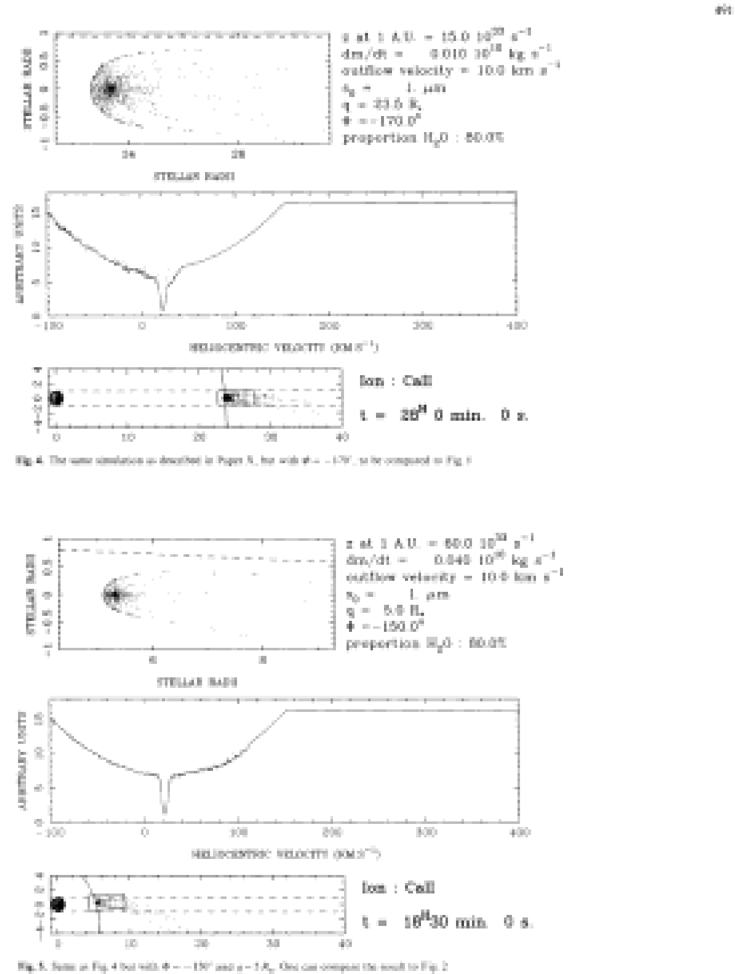
The Falling Bodies scenario

Beust et al. 1990 - 2004

Can explain many gas characteristics:

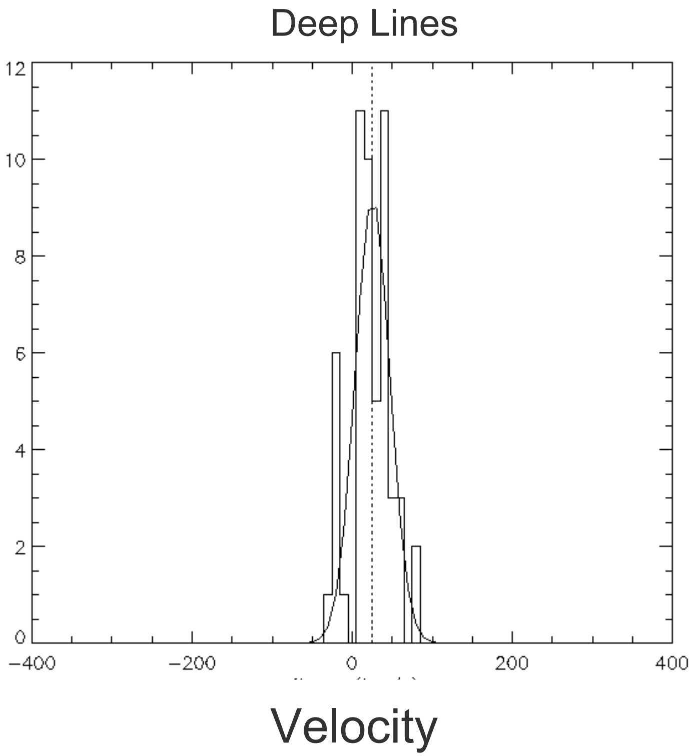
- Clumpiness
- Variability
- Composition
- Recent injection
- Temperature of hot gas
- Highly ionized species

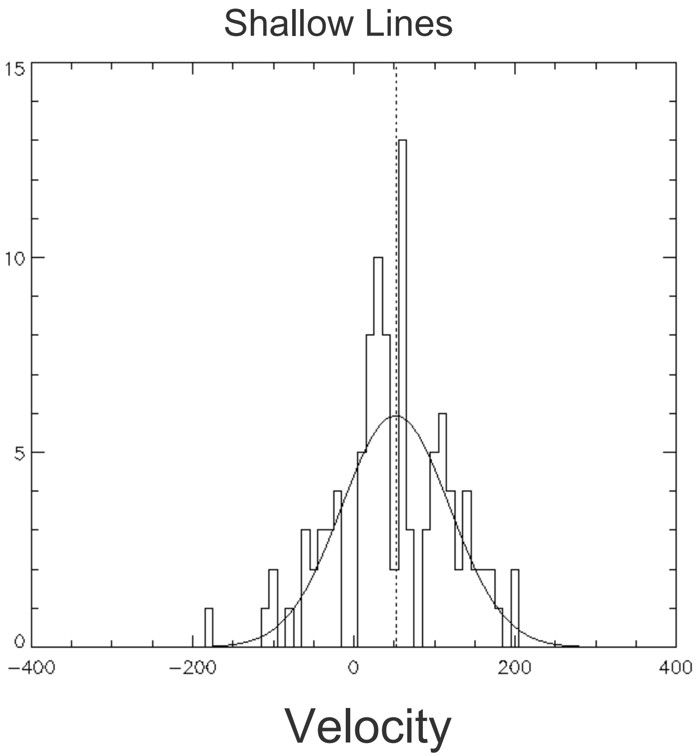
But can not explain distant gas characteristics (from 1 to 300 AU)



Vidal-Madjar et al. 2004

New HARPS Observations: Two FEBs populations





	Deep lines	Shallow lines
Position	25 +/- 5 km/s	48 +/- 5km/s
FWHM	21+/- 2 km/s	70 +/- 7km/s

Vidal-Madjar et al. 2004

Other gaseous debris disks ?

Despite many searches, very few were found :

Emission

- H_2 detected in **β Pictoris, 49 Ceti and HD135344** *(Thi et al. 2001)*
  but not confirmed in β Pictoris *(see Poster by Chen et al.)*
- Fe II possible **β Pictoris** detection *(Lecavelier des Etangs et al. 2002)*
- C II possible **β Pictoris** detection *(Kamp et al. 2003)*
- CO in AB Aurigae, HD 141569 *(Brittain et al. 2003, Augereau et al.)*

Absorption

- **HR 10, HR 9043, HR 2174** *(Lagrange-Henri et al . 1990, 1991)*
- **HD 88195, HD 148283** *(Grady et al. 1996)*
- **HR 10, HR 2174, 51 Oph** *(Lecavelier des Etangs et al. 1997)*
- **HD 100546** *(Grady et al. 1997)*
- **HR 10, HD 85905** *(Welsh et al. 1998)*
- **AB Aurigae** *(Grady et al. 1999, Roberge et al. 2001)*
- **51 Oph** *(Roberge et al. 2002)*
- **HR 2550, HR 3685** *(Hempel & Schmitt 2003)*
- **HD 100546, HD 163296** *(Lecavelier des Etangs et al. 2003)*
- **HD 100546** *(Deleuil et al. 2004)*

This seems to indicate that after ~10 Myr
the gaseous part of a debris disks disappears quickly.

Age of β Pictoris activity

Dust stream (AMOR) reveals a recent outburst ?

Krivov et al. 2004

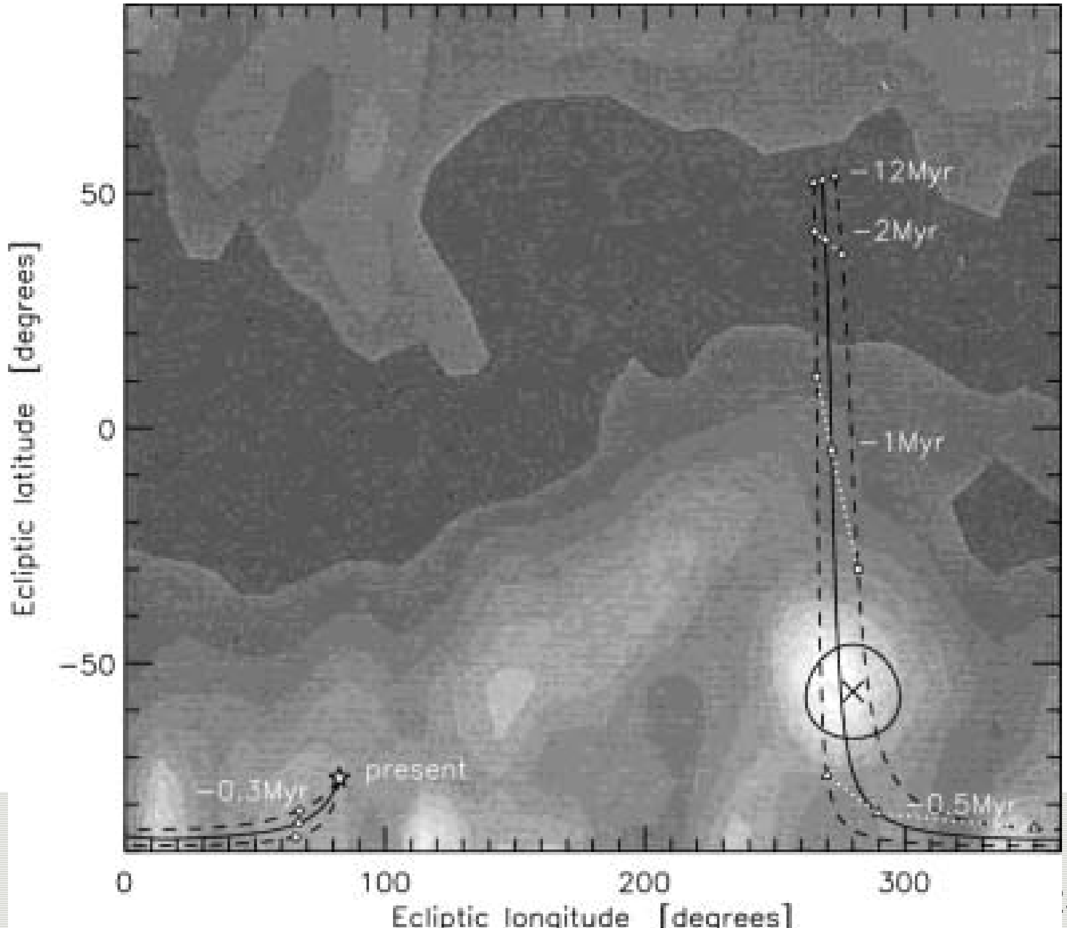
Stream of ~ 20 μ dust grains entering the solar system at 11 km/s

Direction and speed compatible only with β Pic

Ejection speed at source : 25 km/s
Distance of β Pic at ejection : 8 pc
Travel time of dust : 0.75 My

Grains ejected at :
spot upper edge 0.85 My ago at 22 km/s
spot lower edge 0.65 My ago at 29 km/s

Start time well constrained by slower grains more numerous and not detected. End time could be due to rapid drop of faster grains population.



Vidal-Madjar et al. 2004

Conclusion : a giant impact phase ?

Gas in debris disks does not last long, not much more than 10 Myr. Very few gas detections in older systems.

At least in the β Pictoris case, an extremely active phase started at about 10 Myr of the system age.

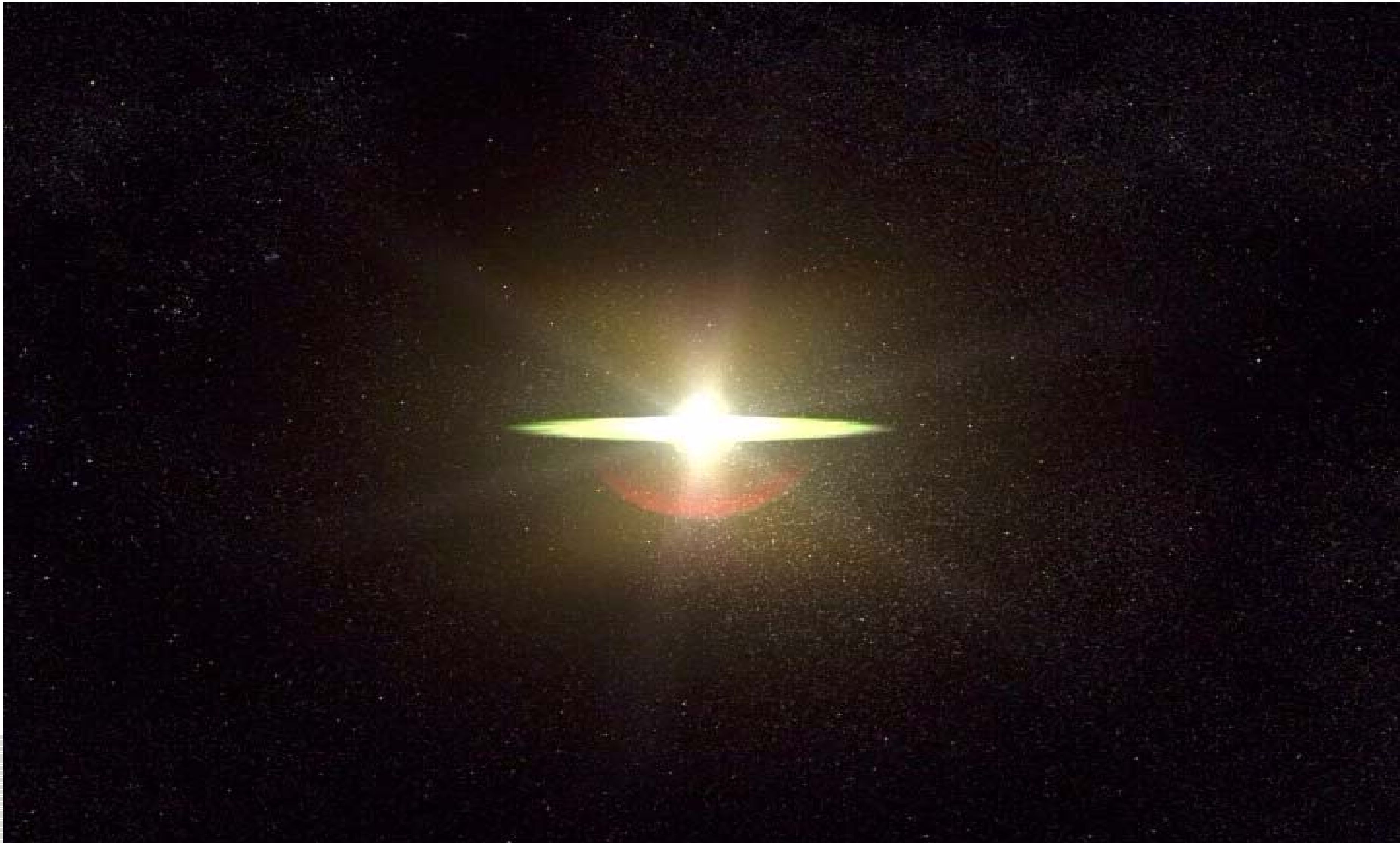
This phase cannot last very long, possibly about 1 Myr (since the β Pictoris system is still active today).

A new type of activity may have been identified, short lived, when «many» large size objects still float around producing possibly «giant» impacts similar to the ones supposed to have taken place in the solar system (formation of the moon, etc…).

Vidal-Madjar et al. 2004

Just for the fun:

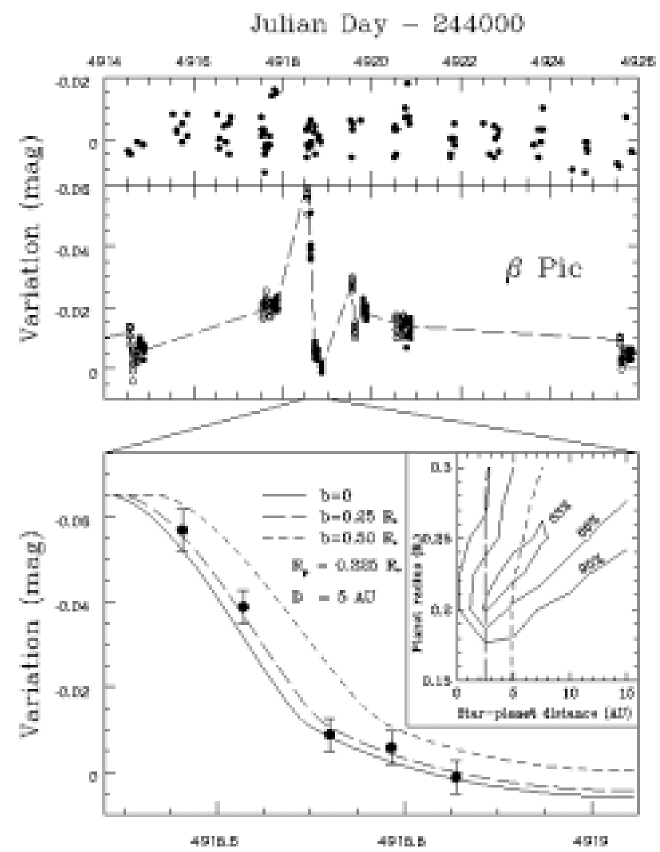
Journey into the β Pictoris system



Consequence : Planets are needed

For many different reasons:

- Inner outer disk wrap, tilt, asymmetry, structure
- To place FEBs on infalling orbits
- To have migrating OEBs
- To explain the peculiar "transit" observed on November 10, 1981



Lecavelier des Etangs et al. 1994
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Vidal-Madjar et al. 1998

Consequence : Planets are needed
Advanced Meteor Orbit Radar (AMOR)
Earth-impacting meteoroïds (20 µm)

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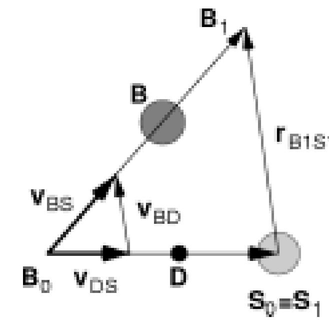
Krivov et al. 2004



- **Inner outer disk wrap, tilt, asymmetry, structure**
- **To place FEBs on infalling orbits**
- **To have migrating OEBs**
- **To explain the peculiar "transit" observed on November 10, 1981**
- **Two populations of FEBs identified**
- **To explain the Beta Pic collimated interstellar meteoroïd dust stream**